

Application of UAV remote sensing in natural disaster monitoring and early warning: an example of flood and mudslide and earthquake disasters

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Abstract. As the frequency and complexity of natural disasters increase, effective monitoring and early warning have become important for the protection of life and property. This paper discusses the role of unmanned aerial vehicle (UAV) remote sensing technology in natural disaster monitoring and early warning. The research in this paper finds that the advantages of UAVs, which carry multiple sensors and are convenient and dexterous, are conducive to natural disaster monitoring. The article then provides examples of UAV applications in different natural disaster scenarios, including monitoring, early warning, post-disaster assessment and ecological restoration in floods, mudslides and earthquakes. In flood monitoring, UAVs equipped with various sensors, such as multi-spectral sensors and infrared thermal imagers, can quickly scan flood-prone areas and transmit data in real time for timely warning and rescue. In mudslide monitoring, drones can collect data such as surface temperature, soil moisture and vegetation health to help identify signs of potential danger. In earthquake monitoring, drones can provide high-resolution images and video to assess earthquake damage and the condition of infrastructure. The future technological innovation and industry development of UAV remote sensing will continue to progress in terms of sensor technology innovation, application of machine learning and artificial intelligence, range extension, and convergence of communication technologies. The significance of this paper is to highlight the importance of UAV remote sensing in natural disaster management and to provide a vision for future research and applications. Drones will continue to play a key role in facilitating the efficiency and accuracy of natural disaster monitoring and early warning to better address potential threats.

Keywords: RS, UAV, Application, Earthquake disasters.

1. Introduction

Natural disasters are an inevitable occurrence on Earth, notorious for their sudden and devastating power. These include floods, landslides, and earthquakes, among others, which have caused significant damage to both life and property in numerous instances throughout history. The earthquake that struck Haiti in 2010 resulted in the loss of 159,000 lives, 316,000 injuries, and the evacuation of 1.3 million individuals. Similarly, Nepal's 7.8 magnitude earthquake in 2015 claimed the lives of 9,000 people and caused injuries to 23,000. The rehabilitation costs incurred because of these events ran into billions of dollars. In Japan, the 2011 earthquake and tsunami caused economic damage worth nearly 210 billion dollars. Natural disasters are indiscriminate and can pose a threat regardless of people's location [1]. Therefore, Immediate efficacy in tools and techniques to combat these dangers is required, with the aim of curtailing damage inflicted by natural disasters.

People have long relied on traditional methods to monitor and manage natural disasters, including ground-based observations, weather stations, satellite imagery and human patrols. However, these methods have serious limitations. Ground-based observations are often limited by geography and resources and do not provide a wide range of information. Weather stations provide weather data, but cannot provide detailed disaster monitoring. Satellite imagery, while providing extensive coverage, is slow to update and weather conditions can affect image quality. Manual patrols, on the other hand, can compromise the safety of personnel, especially in hazardous areas.

Consequently, unmanned aerial vehicle (UAV) remote sensing technology is becoming increasingly important for natural disaster management. Drones provide exceptional maneuverability

and versatility and can be quickly dispatched to affected areas following a disaster. They are fitted with various sensors like high-resolution cameras, thermal imagers, and multispectral sensors, capable of providing high-quality, real-time data. The data helps quickly identify the impacted area, comprehend the damage, and aid in rescue efforts. Furthermore, UAVs can fly over dangerous regions and carry out tasks without endangering human lives.

Therefore, this paper provides an in-depth study of the application of UAV remote sensing technology in the management of natural disasters such as floods, mudslides and earthquakes. The limitations of traditional methods are examined in detail, as well as the advantages of UAV remote sensing technology, including speed, accuracy, coverage and cost-effectiveness. This research will demonstrate how UAV remote sensing can offer new opportunities to improve the efficiency and effectiveness of natural disaster management, thereby reducing the impact on people's lives and the environment. After exploring these aspects in depth, it is expected to provide valuable insights and recommendations for future natural disaster management and post-disaster recovery.

2. Unmanned aerial vehicles remote sensing

2.1. Drones

A drone is an unmanned vehicle that can be flown remotely or along a pre-programmed path, also known as a UAV. The operating principle of UAVs is based on the synergy of flight control systems, sensors and communication systems, which enable them to collect precise data in the target area.

UAVs require real-time communication with ground stations or operators to receive commands, transmit data and report status. Communication equipment typically includes radio links, satellite communications and cellular network connections, and these communication channels ensure that drones can operate remotely in different environments. During emergency rescue missions, drones can receive navigation commands via radio links to quickly reach the target location, while transmitting real-time images back to the ground to help rescuers make decisions. Satellite communications equipment extends the range of drones and is important for monitoring natural disasters in remote areas or for border patrols. Cellular communications can be used as a backup communication method in situations where other communication links may fail.

UAVs can be classified into several types based on their purpose and design characteristics, including fixed-wing, multi-rotor and vertical take-off and landing. Multi-rotor UAVs typically adopt an X, H or four-axis layout to achieve vertical take-off and landing and hover capabilities. Their relatively simple airframe structure and excellent hovering capabilities make them suitable for missions that require low-level hovering and precise manoeuvring, such as aerial photography and search and rescue. In contrast, fixed-wing UAVs have a wing-like fuselage design. This design provides higher flight speeds and endurance and is suitable for missions that require wide area coverage, such as geographic mapping and border patrol. Hybrid UAVs, on the other hand, incorporate multi-rotor and fixed-wing design features with vertical take-off and landing and high-speed cruise capabilities. This design allows the hybrid UAV to flexibly adapt to different mission requirements while introducing additional airframe design and engineering challenges.

2.2. Sensors

UAVs use a range of sensors for remote sensing, such as RGB cameras for producing colour photographs and maps, multispectral cameras for analyzing vegetation health, infrared cameras for thermal radiation data, radar for digital terrain modelling (DTM), meteorological sensors for monitoring atmospheric conditions, infrared cameras for observing hotspots and thermal radiation, and gas sensors for detecting atmospheric concentrations. These sensors are used for a wide range of purposes, including mapping, land use classification, environmental monitoring and natural disaster monitoring. Infrared cameras collect thermal radiation data, measure surface temperature, detect vegetation health and monitor hotspots. In disaster monitoring, infrared cameras are valuable for detecting fires and hot spots. Radar sensors, such as laser radar (LiDAR), penetrate clouds and

vegetation to provide surface elevation data. Meteorological sensors measure atmospheric conditions such as temperature, humidity, air pressure and wind speed for natural disaster monitoring. Infrared cameras capture heat distribution, monitor hot spots and heat radiation, and analyse the thermal performance of buildings. Gas sensors detect the concentration of various gases in the atmosphere and are used for hazardous gas detection in fire monitoring. Combined, these sensors can provide a large amount of data for analysis of geographic features, environmental changes and natural disasters.

2.3. Software system of UAV system

2.3.1. Flight control software

Flight control software, as the intelligent core of the UAV, has the key responsibility of enabling the UAV to fly smoothly and carry out missions. These software systems are similar to the brain of the UAV, not only monitoring the flight status but also responsible for responding to commands from the operator in real time, as well as maintaining flight stability and safety. The flight control software automatically adjusts the vehicle's manoeuvres based on sensor data and pre-set targets to ensure it stays on the desired trajectory. In addition to flight stability, the flight control software has advanced features such as path planning, obstacle avoidance and autonomous flight. These features enable UAVs to perform tasks in complex environments, such as autonomous patrols, search and rescue or mapping. The intelligence of the flight control software enables the UAV to better adapt to the needs of different tasks and achieve high-precision mission execution.

2.3.2. Remote sensing data processing software

Remote sensing data processing software plays a crucial role in UAV systems. They are the key tools for converting raw sensor data into useful information. These data include information from a variety of sensors such as cameras, infrared sensors, LiDAR, etc., which capture various features of the ground or environment. Remote sensing data processing software uses sophisticated algorithms and techniques to analyse, process and visualize these data to generate information that can be used for decision-making and research.

UAV remote sensing monitoring mainly consists of three stages: pre-preparation, aerial photography, and post-processing and analysis. The pre-preparation stage mainly includes steps such as map operation, fixed point survey, flight condition test, route design and flight instruction transmission. The post-processing and analysis stage, mainly includes data download, image processing (image homogenization, stitching, geometric correction, etc.), information extraction and analysis, and information application, as shown in Figure 1.

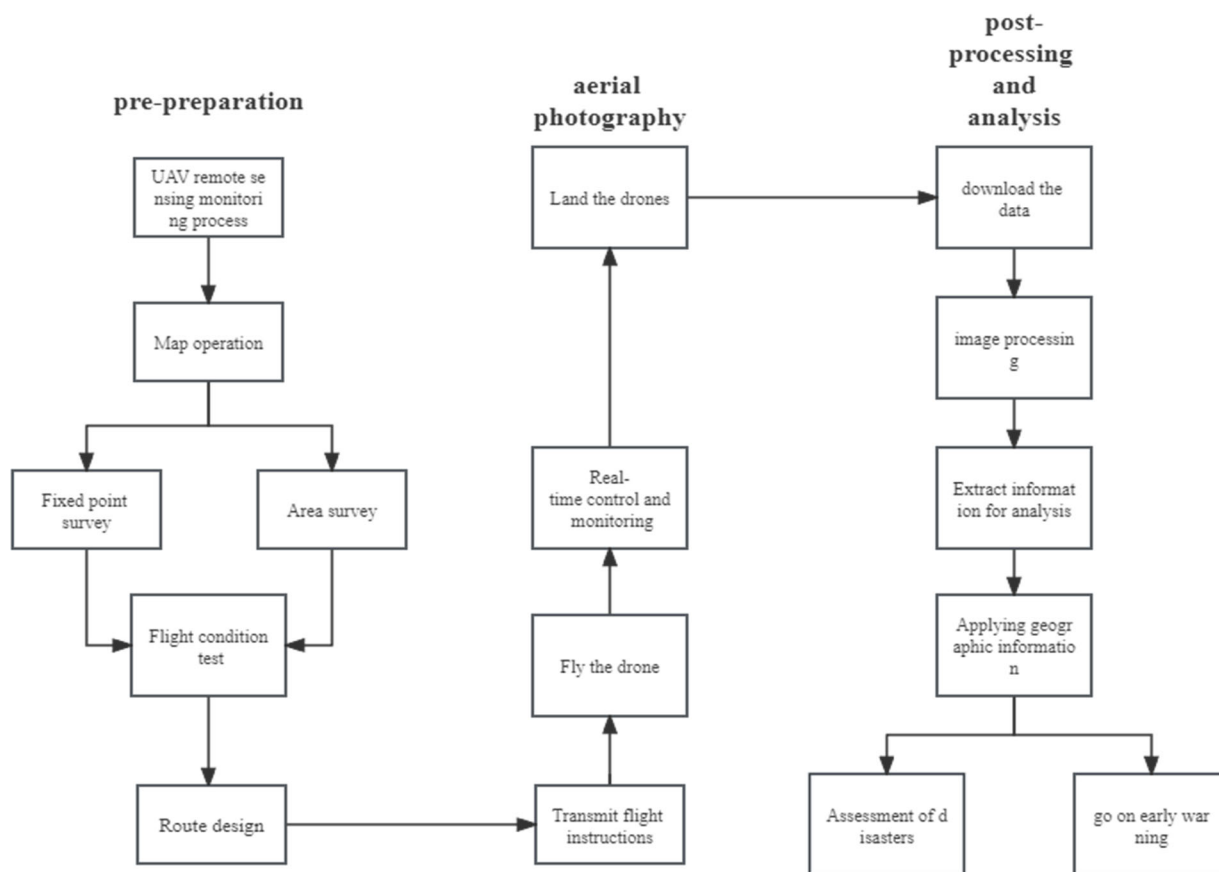


Figure 1. UAV remote sensing monitoring process [2]

2.4. Disadvantages of traditional methods compared to UAV remote sensing

Table 1. Disadvantages of traditional methods compared to UAV remote sensing

Satellite Remote Sensing	Aircraft Remote Sensing	Ground Sensor Networks
Limitations on resolution	Dependence on pilots	Limited space coverage
Limited real-time availability	Limited flexibility	Fixed position
Dependence on weather conditions	Dependence on weather conditions	Dependence on electricity and communications infrastructure
High cost	High cost	Limited height and field vision
Limited by satellite orbit	Regulatory and air traffic control constraints	Difficulty in crossing obstacles

Over an extended period, people have relied on traditional methods to oversee and control natural disasters. These conventional approaches include ground-based sensor networks, meteorological stations, satellite imagery, and human inspections. However, it's important to note that all these methods have significant limitations. Ground-based sensor networks are often constrained by geographic factors and available resources, making it challenging to provide a comprehensive range of information. While meteorological stations offer meteorological data, they fall short of providing precise disaster monitoring capabilities. Satellite imagery, despite its extensive coverage, can suffer from slow updates and be affected by adverse weather conditions, which can degrade image quality. On the other hand, manual patrols can expose personnel to risks, especially in hazardous areas.

3. Application of UAV remote sensing in natural disaster monitoring

3.1. Flooding

Flooding is a common type of natural disaster, often accompanied by heavy rainfall, river overflow or storm triggers. It poses a serious threat to human life and property. In a flood event, time is a critical factor in rescue and response. Traditional flood monitoring methods typically rely on weather stations and manual observation, which suffer from a time lag and do not allow for effective early warning. The emergence of UAV remote sensing technology provides a powerful tool for flood management, facilitating better forecasting, monitoring and response to this disaster. By carrying a variety of sensors, such as multi-spectral sensors and infrared thermal imagers, drones can quickly scan flood-prone areas and transmit data in real time to monitoring stations or command centres. Using the data from the UAVs and flood data models, monitors can get an accurate picture of the depth, speed and extent of flooding, enabling timely rescue operations.

From a hydrological research perspective, three-dimensional (3D) terrain models of complex watercourses can be created based on UAV data, which have a very high level of accuracy and can be used for detailed analyses of runoff and fluvial processes. UAVs can be used to update distributed flood path model boundary conditions and to update model parameters, and Karamuz et al. have developed a procedure that includes the use of UAVs to collect distributed observations of missing river banks to improve the reliability of model predictions and resulting flood hazard maps. UAVs can be used to effectively align flood data with high-resolution and more accurate identification of inundated areas in complex urban landscapes as well as areas inaccessible due to hazardous environments compared to other data acquisition methods [3].

In addition, high-resolution flood propagation and inundation modelling can be achieved using UAV-based LiDAR technology to provide finer DEMs for flood management. This approach enables DEMs with an accuracy of ± 3 cm, overcoming the challenge of collecting detailed topographic data, which is essential for flood modelling [4].

For example, for flood modelling, the researchers manually controlled the course and altitude of the UAV to collect data for the 2015 flash floods in the Shimen River Valley in China due to a reservoir burst and urban flooding in Fengxi New City in Xi'an City, China, using high-resolution digital elevation models (DEMs) and hydrodynamic models and successfully depicted the process of water accumulation in the city using high-resolution LiDAR.

After a flood, it is crucial to understand the situation in the affected area to target and allocate relief resources. Drones play an important role in this. By flying over flooded areas, drones can capture real-time images and video of the affected areas. This data helps to assess damage and identify damaged infrastructure such as buildings, roads and bridges. This information not only helps decision-makers prioritise the allocation of rescue resources but also ensures the safety of rescue teams and avoids dangerous locations. KIM D S et al. have developed drones with intelligent black boxes. This UAS can respond quickly to disasters minimise damage, and automatically report when an accident or hazard is detected for rapid response and remediation, as well as secondary accident prevention [5].

3.2. Mudslides

Mudslides are natural disasters that often cause massive destruction in mountainous areas and adjacent regions. UAV technology plays a key role in mudslide monitoring, emergency response and post-disaster assessment. In this section, we present examples of UAV applications in mudslide monitoring and management, as well as lessons learned.

(1) Monitoring and early warning

The photogrammetric capability of UAVs plays an important role in mudslide monitoring. In areas with a high incidence of mudslides, UAV technology has been widely used to monitor geological changes and rainfall conditions.

Using drones equipped with multi-spectral and thermal imaging sensors, data such as surface temperature, soil moisture and vegetation health can be collected regularly. This data is combined with historical records to help identify signs of potential mudslide hazards. In places such as the Illgraben in Switzerland, researchers such as Walter, Fabian and others have successfully used drone data comparison and analysis to detect signs of terrain change and predict where mudslides are likely to occur so that precautions can be taken in advance. The application of this technology is expected to improve monitoring efficiency and reduce potential disaster losses in areas with a high incidence of mudslides [6]. Zhou, B et al. developed a UAV system that can be used to effectively monitor natural disasters such as mudslides and landslides. The system has an Internet of Things (IoT) data acquisition module that can acquire geological monitoring data of the monitoring area, determine whether the monitoring area has reached the preset warning level, and generate warning alerts for the monitoring area that has reached the warning level [7].

By carrying high-resolution cameras and LiDAR sensors, the drone can capture fine details of the terrain, including mountainous landforms, river contours and vegetation distribution. These data are not only used for geological characterization before mudslides but can also be used to build high-precision mudslide models. Ganghai Huang et al. numerically simulated three potential mudslide scenarios in the Dotang area based on photogrammetry from a UAV. Recommendations for engineering disaster prevention were then made based on the simulation results [8].

(2) Post-disaster assessment

After a mudslide, UAVs can quickly access the affected area to provide a detailed disaster assessment. Sensors and cameras can capture ground damage, road closures, building damage and possible casualties. This data is critical for emergency teams to make decisions, such as identifying the area's most in need of assistance, planning the best rescue routes, and assessing the impact of the disaster on infrastructure. Zhou Xiaolong Guo Fuyun et al. used a DJI Elf Phantom 4 RTK drone to collect and process aerial survey data for the landslide-mudslide disaster in Lijie Beishan, Zhouqu County, Gansu Province and quickly collected relevant parameters such as landslide morphology characteristics, mudslide channel characteristics, analysed signs of landslide deformation, conducted aerial survey accuracy evaluation analysis, and quickly collected basic mapping data in the disaster area, saving time and cost in the emergency response to the geological disaster. Disposal saves time and cost [9].

(3) Environmental restoration and prevention

In addition to monitoring and emergency response, UAVs can also be used for ecological restoration and prevention in mudslide risk management. The potential hazard of mudslides can be reduced by planting vegetation and stabilizing the land. Drones can carry out rapid assessments of vegetation cover to identify the most suitable sites for planting and monitoring during the restoration process. Based on the analysis of the profile and development characteristics of mudslides in Henan Province, Li Weiya used UAV remote sensing monitoring technology to produce regional image maps and identify vegetation ecosystem data sources. This approach has been adopted in the Rocky Mountain region of Colorado, USA, where drones have been used to monitor vegetation recovery in areas potentially at risk from mudslides. This helps to ensure that vegetation can help stabilise the soil and reduce the risk of mudslides [10].

3.3. Earthquakes

Earthquakes are one of the most destructive natural disasters, often resulting in the collapse of buildings, loss of life and catastrophe for communities. UAV technology has begun to play an increasingly important role in earthquake management and relief, providing critical information and support. In the aftermath of an earthquake, drones can take off quickly and fly over affected areas to capture high-resolution images and video. This data can provide critical information on earthquake damage, road conditions and potential hazards. This helps decision-makers better understand the situation in affected areas, plan rescue operations and ensure the safety of rescue teams.

(1) Earthquake damage assessment

After an earthquake, there is often a need to quickly understand the situation in the affected area to carry out emergency rescue and post-disaster recovery operations. Traditional methods usually face communication disruptions, road blockages and hazardous situations, making it difficult to obtain accurate information on time. The use of drones can change this. The post-earthquake seismic landslide identification model, based on UAV remote sensing data from past earthquakes, has good versatility and transferability. It has good application potential in earthquake disaster emergency response and can provide strong support for post-earthquake emergency rescue and disaster assessment. Fu. R et al. used the 2008 post-earthquake unmanned aerial vehicle (UAV) remote sensing images of Wenchuan County, Sichuan Province, China as a data source, and used a well-trained model to identify landslides caused by earthquakes in Haiti, proving the accuracy of the model [11].

(2) Infrastructure inspection

Earthquakes often cause severe damage to infrastructure such as bridges, roads, pipelines and power lines. By carrying high-resolution cameras and sensors, drones can fly over affected areas and capture images and data that can be used to quickly inspect the condition of this infrastructure. This data can be used to assess the extent of damage and determine where urgent repairs are needed and where they are unsafe. This is critical for repairing infrastructure, restoring traffic and providing electricity. Ye et al. used a large dataset of UAV imagery for experimental validation to demonstrate the performance of their proposed Multi-task High Resolution Network (MT-HRNet) damage identification model. The model can be used to quickly determine the structural safety level of bridges after earthquakes and take appropriate management actions [12].

By using historical earthquake data for model training and fine-tuning the model after a new earthquake, Hong Zhonghua et al. were able to classify damaged buildings quickly and accurately, improving the ability to classify buildings with different damage levels [13].

(3) Post-disaster recovery and planning

Earthquakes often leave long-term damage and require long-term recovery and planning efforts. UAV technology can also play a role here. Highly accurate terrain models and 3D maps can be produced using UAVs, which are essential for planning urban reconstruction, road rehabilitation and infrastructure upgrades. Diazeng Shan et al. focused on measuring the tilt angle of UAVs, comparing the effects of the performance of different software packages, UAV flight modes and the number of GCPs on the accuracy of the models. The results show that point cloud models generated by image processing have potential for structural damage detection, and that UAVs combined with image processing and point cloud modelling techniques are capable of generating highly accurate 3D point cloud models. The combination of UAV and image processing techniques provides highly accurate terrain models and 3D maps for planning projects such as urban redevelopment, road rehabilitation and infrastructure upgrades, providing important support for decision-making and project management [14].

In addition, the monitoring capability of UAVs can also be used to track geological activity following earthquakes, as well as potential secondary hazards such as landslides and mudslides. Chen et al. used data from the MS 7.4 Maduo earthquake to train an image segmentation algorithm to build a model that can automatically identify and map small and irregular surface cracks from high-resolution UAV images, which can be used to monitor ground cracks after earthquakes to prevent secondary disasters [15].

4. Future trends in drone technology for natural disaster monitoring and early warning

4.1. Technological innovation

Sensors are at the heart of UAVs, and future sensors will be more powerful, diverse and accurate. High-resolution multispectral and hyperspectral cameras will be able to capture more details of the

ground surface, including information on vegetation health, soil moisture content, etc., which is crucial for monitoring and early warning of natural disasters such as floods. In addition, high-precision LiDAR sensors will provide more detailed terrain data that can help to accurately model the spread of floods, mudslides and landslides. In addition, drones can improve detection by combining data from multiple sensors. These methods can use multiple sensors, such as visible cameras, infrared cameras and audio signals, for better results.

Machine learning and artificial intelligence will also be important drivers of drone technology. Future drones will not only be data collectors but also data analysts. DOMITRAN et al. used the Unity engine and deep reinforcement learning algorithms to create, develop and test an ML agent simulation environment. In this simulation environment, UAVs are given the ability to fly using deep reinforcement learning algorithms and also learn to perform specific tasks in this environment. By using deep learning algorithms, the UAV can learn to detect signs of disasters, such as building damage after an earthquake and people trapped in a flood. This would greatly speed up data processing and allow decision-makers to act more quickly [16].

The range of drones will also improve significantly. Battery technology for drones will become more efficient and power systems will become more energy-efficient, allowing drones to fly longer and cover larger areas on a single charge or fuel fill. Shun YAMATE compared the environmental impact of different types of batteries for drones during the manufacturing and use phases of a drone, pointing to the increased flight time and reduced environmental impact of UAS using biohydrogen fuel cells.

Another key technological innovation is the integration of communication technologies. Satellite communications and 5G technologies will further enhance the communication capabilities of UAVs. This means that drones can transmit data over greater distances and in complex environments, enabling them to monitor remote areas while maintaining real-time contact with ground stations. This is critical for disaster risk monitoring and emergency response in remote areas [17].

4.2. Industry trends

In the future, the natural disaster management industry will see several emerging trends that will have a profound impact on the adoption and market demand for UAV technology.

Data integration and sharing will be key. The natural disaster management sector will place greater emphasis on the integration and sharing of multiple data sources, including drones, satellites, sensors and ground monitoring stations. This will provide decision-makers with more comprehensive information and a better understanding of natural disaster trends.

International cooperation will increase. Transnational cooperation will enable countries to share technology, data and best practices to better respond to transboundary natural disasters, such as regional outbreaks and flood risks on transboundary rivers. International cooperation will also accelerate technological innovation and capacity building.

Regulation and standardization will play a greater role. To ensure the compliance and safety of drones in natural disaster management, governments and international organisations will continue to develop regulations and standards. Ivo Stancic et al. have proposed that the problem of using machine learning methods to classify flying objects in low-resolution video can quickly detect and identify potentially malicious drones. This will help regulate the use of drones to ensure that they do not interfere with rescue efforts or affect the public [18].

5. Conclusion

This paper has analysed the main applications of UAV remote sensing technology in this field from the perspective of natural disaster monitoring and early warning. UAV remote sensing has the advantages of multiple sensors, high resolution imaging and remote communication. These features make UAV remote sensing an ideal tool for natural disaster monitoring and early warning. In flood monitoring, by carrying a variety of sensors, such as multi-spectral sensors and infrared thermal

imagers, UAVs can quickly scan flood-prone areas and transmit data in real time to monitoring stations or command centres, so that monitors can accurately understand the depth, speed and extent of flooding, and thus take timely rescue action. At the same time, UAVs combined with remote sensing data can provide critical data in real time to assist in the allocation of rescue resources and risk assessment. In mudslide monitoring and management, remote sensing data collected by drones can help identify signs of potential mudslide hazards. UAV remote sensing plays an important role in geological change monitoring, post-disaster assessment and ecological restoration. During seismic events, UAV remote sensing can play a key role in earthquake damage assessment, infrastructure inspection and post-disaster recovery planning. Particularly in the immediate aftermath of an earthquake, drones quickly take off and fly over affected areas, capturing high-resolution images and video that provide critical information to help decision-makers understand the damage, plan rescue operations and ensure the safety of rescue teams.

Future trends include more advanced sensor technology, the application of machine learning and artificial intelligence, and increased range and integration with communications technology. These trends will enable drones to provide more accurate and real-time data, contributing to early warning and more effective responses to various natural disasters. In addition, natural disaster management will emphasise data integration and international cooperation to improve the overall capacity to respond to natural disasters and will continue to push for regulation and standardisation to ensure drone compliance and safety. In summary, the application of drone technology in the field of natural disaster monitoring and early warning is promising and of great importance in reducing losses, improving emergency response and protecting social security. Continued research and innovation in this area will provide more effective tools and methods for natural disaster management in the future.

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